AVERAGE REGIONAL SLOPE, A CRITERION FOR THE SUBDIVISION OF OLD EROSION SURFACES[1]

LEOPOLD REINECKE
Geological Survey of Canada

CONTENTS

INTRODUCTION

During the four field seasons from 1908 to 1911 the writer was engaged in topographic and geologic work in the southern part of the Interior Plateaus of British Columbia. Certain questions which arose in the study of the physiography of that region are discussed in this paper.

Information regarding the physiography was acquired from a study of the Tulameen and Beaverdell map areas at the Southern end of the Plateaus, of the Kamloops and Shuswap[2] map sheets covering 9,000 square miles to the north of them, and from the

[1] Published by the permission of the Director of the Geological Survey of Canada.

[2] The geological work upon the Tulameen map area was done by C. Camsell, and upon the Kamloops and Shuswap areas by G. M. Dawson of the Geological Survey of Canada. Explorations in the country between these areas have been made by the same men.

descriptions of the region lying between. The locations of the areas in question and of the Interior Plateaus are shown on the index map, Fig. 1. No detailed work has been done to the north of the Kamloops area, but explorations have indicated that the

FIG. 1.—Index map

character of the surface resembles that farther south although the general elevation is said to be less.

The southern part of the Plateaus consists of an old erosion surface or upland, dissected by younger deep valleys (Figs. 2, 3, and 4). The region appears to have been overridden by a conti-

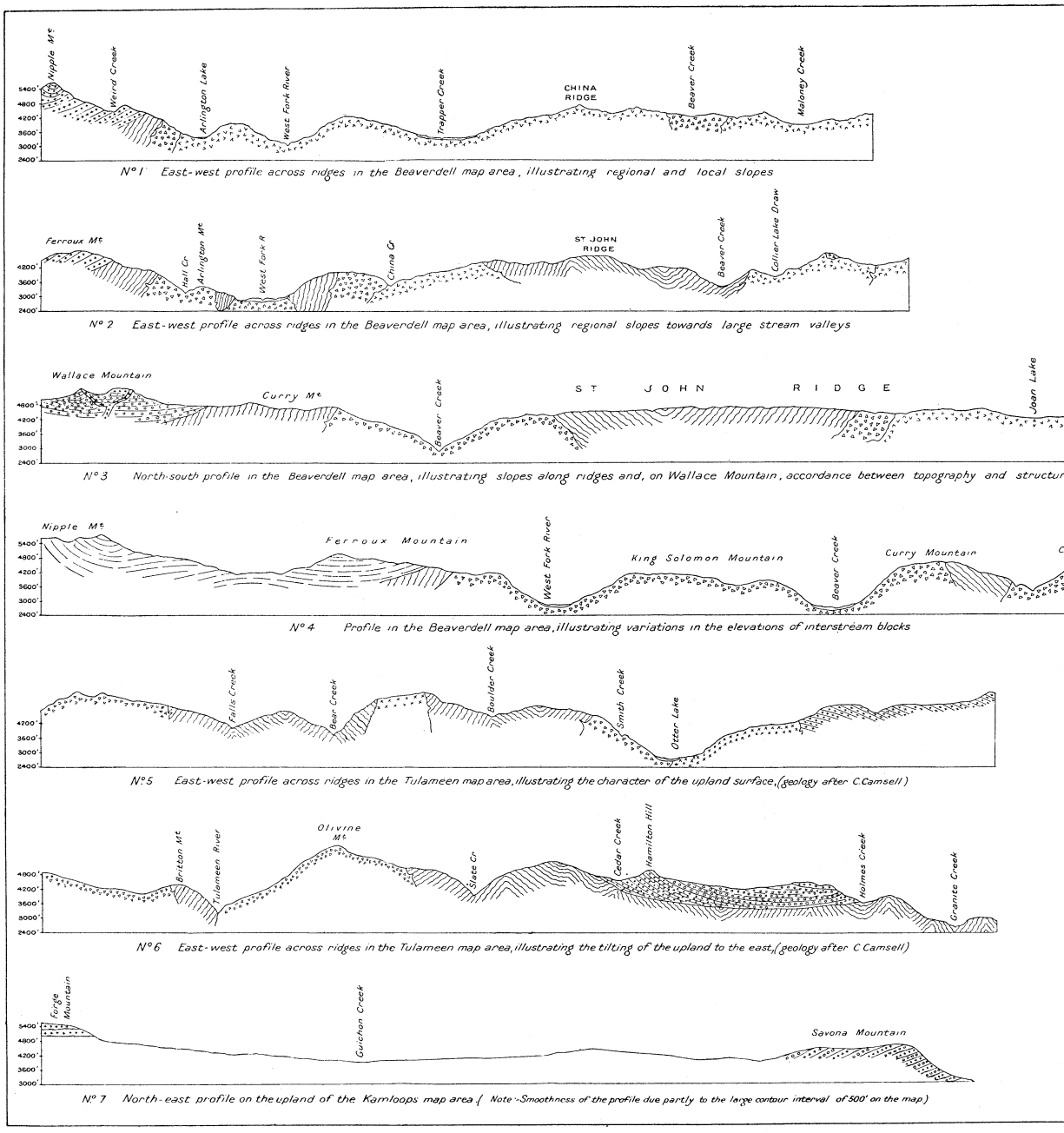
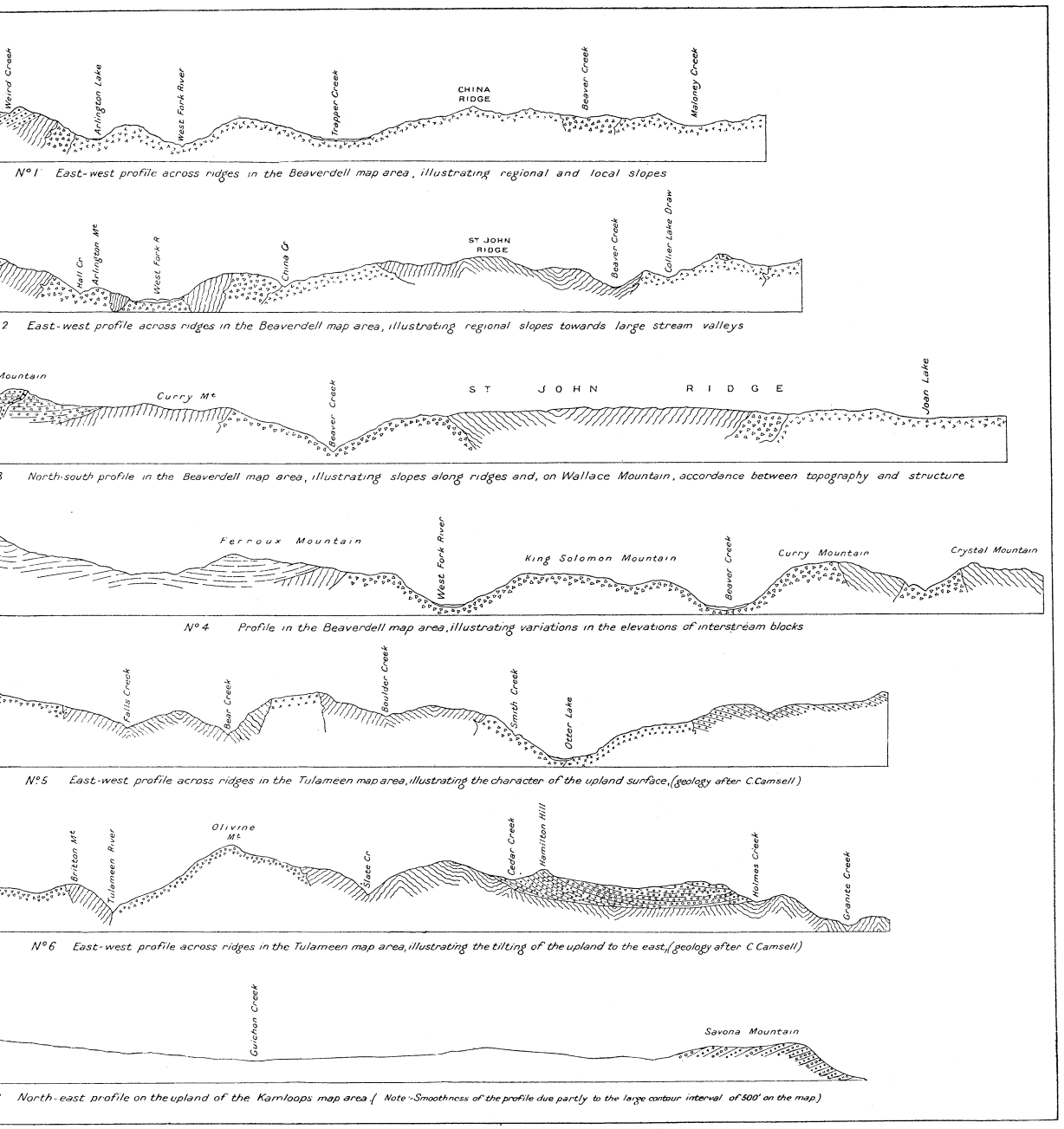


FIG. 2.—Character of the surface in the Interior Plateaus of British Columbia. Horizontal scale: 1 in. = about 2$\frac{2}{7}$ mil



IG. 2.—Character of the surface in the Interior Plateaus of British Columbia. Horizontal scale: 1 in. = about $2\frac{2}{7}$ miles

nental ice sheet which removed the soil covering from the upland, carved a few shallow rock basins, and left a thin irregular blanket of drift upon its retreat, but which does not appear to have modified the upland slopes in any essential manner. This old upland surface has all the essential characters which are commonly used as criteria to distinguish peneplains, but the average slopes on it, measured from the higher areas or ridges toward main drainage lines, vary from 150 to over 300 feet to the mile, and these slopes

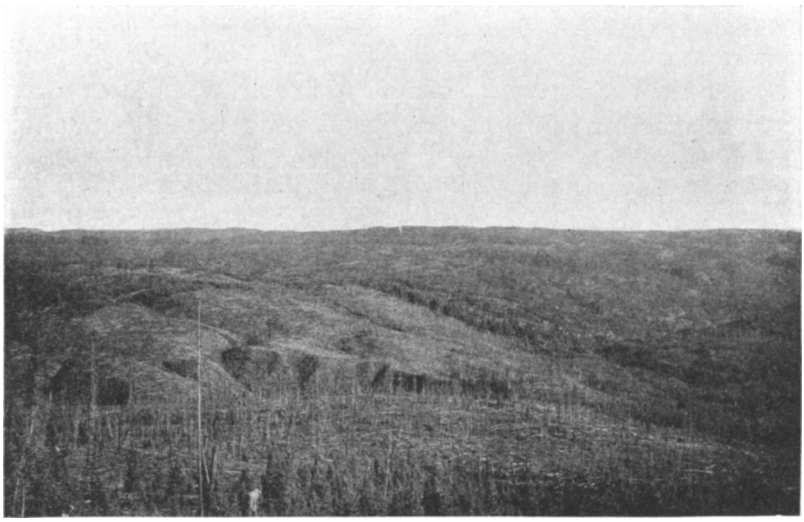


FIG. 3.—View of a portion of the Interior Plateaus near the Tulameen Valley

are found on the surface as a whole, not merely on isolated portions of it.

If the slopes on this land form had not been measured, the dominant discordance of topography and structure and the general evenness of sky line would have caused it to be classed as a peneplain. The degree of slope present, however, led to a search for indications that would point to the fact that in this instance the stage of old age had just begun. It was found that the drainage system upon the upland was apparently related to a system of shear zones in the underlying rocks, and that in some of the areas underlain by certain Tertiary sediments and lavas, topographic form was governed by

geological structure. The accordance of topography and structure might in this case be described as a dimmed and accessory character, while the discordance was sharply defined and extensively developed, an essential character. It was found that on an old surface, with slopes of 3 to 6 per cent, the characters developed in maturity were just disappearing and those related to peneplanation were strongly developed but had not yet entirely supplanted the others.

According to the hypothesis of the geographic cycle this land form, if it had been left undisturbed, would have been gradually worn down; that is, its average slopes would have been gradually diminished, the characters of maturity have gradually disappeared, and the characters of peneplanation have prevailed everywhere. It seemed possible then, by using the criterion of regional slopes, to subdivide old land forms on a quantitative basis.

The primary object of this paper is to point out the importance of the measurement of average regional slopes upon "old erosion surfaces," and to show that such data assist materially in the more accurate study of the physiographic development of the region in which these surfaces occur, and of the diastrophic movements which have taken place there. The writer believes that it will be possible eventually to subdivide old land surfaces on the basis of their average slopes, and has attempted to do so here. The subdivision proposed is necessarily imperfect, partly because of the lack of accurate data regarding the slopes of old erosion surfaces, and largely because of the writer's imperfect knowledge of the literature describing such surfaces. As more data upon the slopes of old surfaces become available, however, the imperfections of a subdivision of this kind can be remedied.

METHOD OF MEASURING REGIONAL SLOPES

By regional slope is meant the general slope of the land toward main drainage lines. Slope is stated here as the percentage of vertical to horizontal distance rather than as an angle, because the measurement of the angles of slope on a land form of moderate relief is generally impracticable in the field, and for that reason the degree of slope stated as an angle, especially if the angle is small, does not

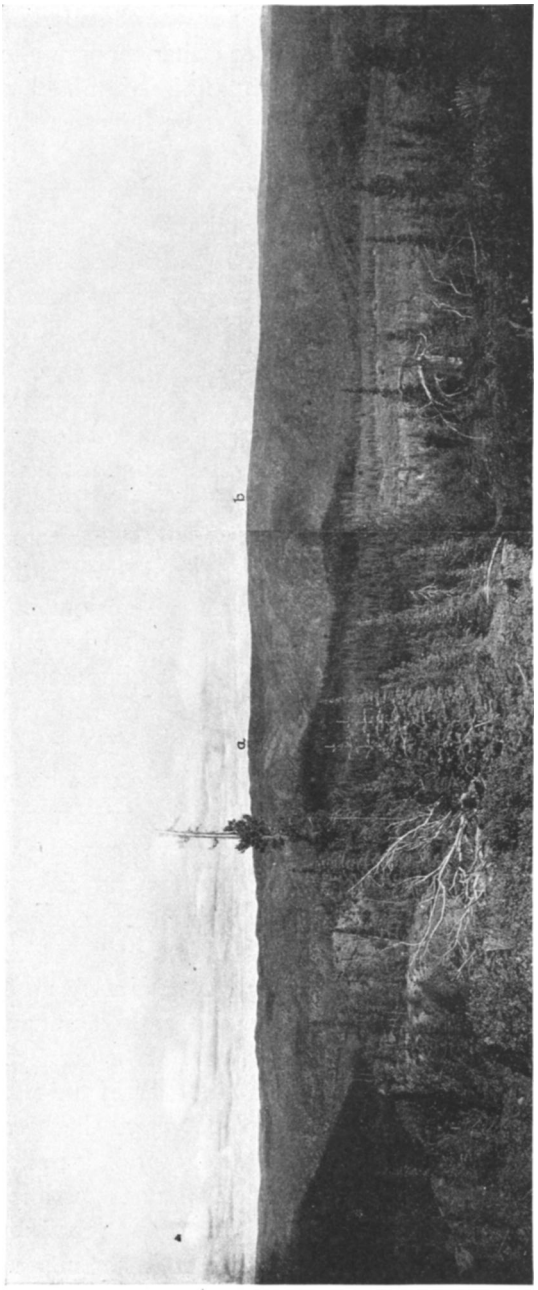


FIG. 4.—View of the Interior Plateaus looking northeast across the valley of the Tulameen River

carry a suggestion of the actual land form to the mind of the reader. For the measurement of such slopes either topographic maps or a number of traverses across the region to be examined are essential. An appreciation of the significance of the slopes can, however, be attained only by traveling over them.

The following is an outline of the methods followed in obtaining data from topographic maps of portions of the southern section of the Interior Plateaus of British Columbia. These methods were applied, in part, to the measuring of slopes upon topographic maps of certain sections of the United States, with satisfactory results.

The first step to be taken is the drawing of a number of profiles, some in the direction of the main drainage and others at right angles to it. The profiles should include as many of the pertinent topographic features of the region as possible. If they are plotted with a vertical scale somewhat larger than the horizontal, they will assist both in determining whether the land form under consideration is the result of one or more cycles of erosion, in discovering whether processes other than subaërial erosion have been responsible for existent forms, and in detecting tilting or warping of the crust subsequent to the formation of the surface. The usefulness of profiles is discussed more fully farther on. If forms due to more than one cycle are present, slopes should of course be measured on each of those forms separately. In the Interior Plateaus two cycles are represented, an older upland and younger valleys intrenched in it. There is a distinct break or topographic unconformity between the upland and the valley forms (Fig. 2, profiles 1 to 7). In this instance the measurements of slopes on the older land form, the upland, were made by taking a large number of horizontal measurements on the topographic map from a dominant ridge line to the bottom of a large upland valley. If a deep valley of the younger cycle occupied the site of the bottom of the old valley, the measurements were made to the point where the break in slope occurred between the old and the young forms (profiles 1 and 2). Horizontal measurements were made as long as possible, and never less than one mile. The vertical difference was read directly from the topographic map. Measurements were taken in both directions

at right angles to the trend of the ridge, and also along its crest. Variations in the slopes along ridge crests in the Beaverdell map area of southern British Columbia are illustrated in Fig. 2, profiles 3 and 4. The average slope measured on four or five ridges in this area lay between 100 and 300 feet to the mile, and averaged over 200 feet except in places where certain Tertiary formations occurred over which the slopes ranged between 500 and 900 feet to the mile, and averaged 600. The Tertiary areas occupied less than one-eighth of the area of the whole upland; the average slope along ridges therefore averaged between 200 and 300 feet to the mile. Slopes across ridges were in this area of very nearly the same magnitude and did not average over 300 feet to the mile.

Slopes as high as 900 to 1,000 feet to the mile were found in a few places only, and could have been omitted from the general average without changing the result to any great extent. Such local irregularities of slope are more likely to occur in land forms with fairly high slopes than in those which are of a plainlike character. Of twelve measurements on the Caldwell, Kansas, map sheet for instance, six lay between 14 and 21 feet to the mile, four between 32 and 35 feet, one was 47 feet, and one 10 feet to the mile.

VALUE OF THE MEASUREMENT OF REGIONAL SLOPES

The study and determination of the regional slopes upon old erosion surfaces is both useful and necessary. It is useful: (*a*) in helping to determine the agencies which have carved and molded the topography to its present form, and (*b*) in separating forms due to different erosion cycles. It becomes necessary (*c*) when an old erosion surface is to be used as a datum for measuring diastrophic movements.

a) The study of regional slopes often will indicate the agencies which have carved or assisted in carving a land form. This is illustrated by Barrell's[1] work along the New England coast. He found that certain flat-topped ridges in the interior sloped gently toward the coast, and the plainlike surfaces, of which the ridge tops were residuals, occurred in terraces of successively higher

[1] Joseph Barrell, "Piedmont Terraces of the Northern Appalachians," *Bull. Geol. Soc. Am.*, XXIV, No. 4 (December, 1913), 688–90.

elevations, each being separated from the next by a shorter and steeper slope. Further study proved that a number of flat hill-tops in this region, which have for a long time been regarded as residuals of a tilted peneplain formed by subaërial erosion, were in reality parts of a series of wave-cut marine terraces.

b) The measurement of slopes and the study of profiles were found very useful in determining the number of cycles of erosion through which the uplands of the Interior Plateaus of British Columbia had passed. The older uplands and younger valley cycles were separated with comparative ease, but detailed study of the slopes was needed to show that no remnants of an older plain-like surface existed within the upland itself.

c) The measurement and recording of regional slopes will be of the greatest value, however, in cases where old surfaces and their residuals are used to determine the manner in which earth movements have taken place or the amount through which a section of the crust has moved. The manner in which movements of the crust have taken place sometimes can be brought out by profiles (see Fig. 2, profile 6), but it is necessary to determine the original internal relief and average slope of an elevated or warped old erosion surface before such a surface can be used for quantitative measurements of movements of the earth's crust.

In the uplands of the Interior Plateaus, for instance, the relative relief of points within 10 miles of each other quite commonly is from 1,500 to 2,000 feet. If such a surface be uplifted and dissected until only remnants of it remain, the difference of elevation between them could be 1,500 feet without the section of the crust within which they occur having been either warped or tilted. Calculations of earth movements based on the assumption that such a surface was plainlike before uplift would be liable to errors of 1,500 feet or more. If the slopes are not measured, however, old surfaces of marked relief are likely to be thought nearly flat or of much lower relief than actually is the case. For instance in describing an old erosion surface in the Colorado Front Range, Davis[1] says: "In the highland west of Palmer Lake, between Denver and Colorado Springs the sky line seems to be essentially

[1] W. M. Davis, "The Colorado Front Range," *Ann. Assoc. Am. Geog.*, I, 42.

level; much more so in the actual view than would be inferred from the crowded contours of the Platte Canyon map sheet."

Value of certain criteria of peneplanation.—The reasons for mistakes of the kind referred to are, first, that an uplifted old erosion surface of moderate relief is often seen in juxtaposition to younger topographic forms upon which the slopes are much steeper, so that by contrast the relief on the older surface appears much less than it really is.

A second and less obvious reason is that certain of the more important characteristics of plainlike erosion surfaces with average slopes of less than 10 feet to the mile are found also on old erosion surfaces with slopes as high as 300 feet to the mile. The criteria referred to are a general flatness of sky line and the planing of a rather flat topographic surface across rocks of different hardness and texture without any apparent change in the character of the topography.

Flat sky lines: In a rolling hill country ridge lines sloping from 100 to 300 feet to the mile may appear quite flat and the completeness of the illusion will depend partly on the position of the observer and partly on the distance of the ridge line or lines from him. Flat sky lines often are caused by the blending of more than one ridge line of entirely different elevation in the observer's line of sight, the irregularities of one being neutralized by the other (Figs. 3 and 4). The writer knows of at least one locality in the Beaverdell map area of British Columbia where an observer, climbing up one side of the West Fork River valley and looking across to the opposite side, would see first a flat sky line on a ridge with an elevation of 4,000 feet, and as he climbed higher another flat ridge line would come into view with an elevation approximately 700 feet higher and lying 3 miles farther away. The two ridges are shown in cross-section in Fig. 2, profile 2, the flat top of the higher, the St. John ridge, in profile 3. Between the two positions there is doubtlessly one where both ridge lines would blend and appear as one. The flat sky line in this instance evidently does not mean that the ridge tops represented in the sky line are remnants of one nearly flat plain, for the lower one is next to a large river, the higher 3 miles from it, and the slope between them over 200 feet to the mile.

Nor can the lower and flatter of the two ridges be considered a peneplain remnant. Both ridges are, in fact, part of one surface in the stage of early old age, a surface with average slopes of about $2\frac{1}{2}$ per cent. Their nearly flat surface is doubtlessly due to their lying between nearly parallel drainage lines.

Measurements made along apparently flat ridges, moreover, often show that they slope at a quite appreciable rate. The slopes upon St. John ridge, one of the ridges referred to in the preceding paragraph (Fig. 2, profile 3), vary from 100 to 300 feet to the mile. In Fig. 4, an apparently flat sky line is shown between the points *a* and *b* which are about $7\frac{1}{2}$ and 6 miles respectively, from the camera. From the photographic work done at this place it is known that a vertical shift of $\frac{1}{100}$ of an inch in the sky line of the picture represents an actual fall of 90 feet in the topography, and that between *a* and *b* there is a broad upland draw which is 250 feet deep, and whose sides slope at the rate of 100 feet to the mile. If the sky line in Fig. 4 were farther away, it would, without doubt, appear much flatter. In the clear western air, ridges 20 miles away often are plainly visible.

Discordance of structure and topography: Discordance of topography and structure must also not be considered a final proof that the land form being examined is at all plainlike. Relatively flat surfaces planing across the contacts of rocks of different hardness are quite common in the Interior Plateaus, but sloping surfaces which plane across the structure are much more common. The flat areas are local developments on the rolling-hill type of Interior Plateau topography. In one instance a flat surface was seen planing across a centroclinal basin of relatively soft rocks which were protected on the outside by hard layers. The flat surface is shown in Fig. 2, profile 6, just east of the point marked Hamilton Hill, and a part of the same surface in the foreground of Fig. 4. This is undoubtedly a case of local base-leveling and not a proof of universal peneplanation. In another locality a flat ridge top lying next to a large river at an elevation of 3,800 feet was found planing across the structure. The ridge, a part of King Solomon Mountain in the Beaverdell area, is shown in cross-section in Fig. 2, profile 4, but the change of structure is not shown in the profile. This ridge

top represents the lowest part of the upland within an area of several hundred square miles and within 10 miles of it there are numerous ridges from 1,000 to 2,000 feet higher. The flat surface is a small but integral part, not of a plainlike, but a decidedly hilly, land form. Discordance between topography and structure is, moreover, as well developed on the sloping hillsides of that land form as on the few flat surfaces that are present within it.

Neither approximately even sky lines, nor flat or nearly flat areas planing across the structure, are therefore in themselves a proof that the land form within which they occur is of more moderate relief than the upland of Interior Plateaus with average slopes as high as 6 per cent. The measurement of the slopes on old erosion surfaces must therefore be made before one can venture to judge of its actual relief or use it in quantitative measurements of earth warping.

PROPOSED SUBDIVISION

The following subdivision is concerned only with the stage of old age in the normal cycle of erosion as outlined by Davis.[1]

An old erosion surface is for the purposes of this discussion defined as a geographic unit worn down by subaërial processes alone to a state of moderate relief. By geographic unit is meant a portion of the earth's surface over which topographic conditions and the underlying rock structure were essentially similar at the beginning of the erosion cycle, and over which conditions of erosion remained essentially the same while the cycle was in progress. It is proposed to treat all surfaces in this stage as varying from two types, those of plainlike forms of peneplains and forms corresponding in general features to the uplands of the Interior Plateaus of British Columbia which may be referred to as "beveled hills." Following Smith[2] and Davis[3] peneplains are defined as geographic units worn down by subaërial processes alone to a condition of very moderate relief. The theory of the formation of such plainlike land forms does not necessarily imply that all parts of them lay

[1] W. M. Davis, "The Geographic Cycle," *Geog. Jour.*, XIV (1899), 481.

[2] W. S. Tangier Smith, "Some Aspects of Erosion in Relation to the Theory of the Peneplain," *Univ. of California Bull. Dept. of Geol.*, II (1899), 155–77.

[3] W. M. Davis, "The Geographic Cycle," *Geog. Jour.*, XIV (1899), 486.

near the ocean at the time of their formation. If the geographic unit be large, parts of it must lie far from the ocean and may be at a considerable elevation above it.[1] The "Almost plains" are characterized as presenting absolute discordance between topography and structure, graded streams and hill slopes, that is, practically a lack of cliff and local flat surfaces, and by deep soil covering. These are the commonly accepted criteria for determining peneplanation. In addition, we suggest that the term be restricted to surfaces with average slopes of less than 2 per cent, 105 feet to the mile. For examples of peneplains one may cite the Laurentian peneplain[2] of Canada, and a peneplain in the Mississippi Valley illustrated by the Caldwell, Kansas, topographic map sheet.[3] The Laurentian peneplain has an area of about two million square miles, with average slopes of about one-tenth of 1 per cent. It differs from an ideal type in that it has been modified by the accident of glaciation in removing the residual soil, in substituting an irregular drift mantle, and in slightly altering the form of the original surface. Upon the Caldwell area, average slopes vary from 10 to 50 feet to the mile, that is from one-fifth of 1 per cent to 1 per cent.

"Beveled hills" are characterized as geographic units worn down to moderate relief by subaërial processes alone. Their "essential" characters are discordance of topography and structure, graded slopes, smooth sky lines and contours, and a deep soil covering. Their "accessory" characters are local accordance between topography and structure, and the local occurrence of cliff faces and flat areas, that is, of ungraded slopes. In this instance the terms "essential" and "accessory" are used in the same way as they are in petrography, essential characters being those which predominate within the land form, accessory those of which but few examples can be found and which may be entirely absent.

"Peneplains" and "beveled hills" are distinguished therefore by their degree of slope and also by the occasional finding in the

[1] W. M. Davis, "The Colorado Front Range," *Ann. Assoc. Am. Geog.*, I, 42.

[2] A. W. G. Wilson, "The Laurentian Peneplain," *Jour. Geol.*, XI (1903), 628–29.

[3] Henry Gannett, "Topographic Atlas of the United States. Physiographic Types," *U.S.G.S.*, Folio 1, Caldwell, Kansas, sheet, 1898.

"beveled hills" type of characters which are characteristic of the stage of maturity.

It is suggested that the upland portion of the Interior Plateaus of British Columbia be taken as a type of the "beveled hills" form, and that the term therefore be restricted to old erosion surfaces upon which the average regional slopes are from 3 to 6 per cent. The upland of the Plateaus differs from an ideal type in that glaciation has removed the soil covering and substituted an irregular mantle of drift.

The term "beveling" was introduced into physiographic literature by Tarr.[1] He applied the term to the process of the cutting down of certain of the peaks and ridges on a land form, by differential erosion, to approximately uniform elevations. According to Murray's *New Dictionary* one of the meanings of "to bevel" is "to reduce (a square edge) to a more obtuse angle." As used in this paper the adjective "beveled" is meant to suggest that the land form so designated has been reduced to one on which nearly uniform sky lines are a common characteristic, and one upon which ridge tops have broadened or become rounded in cross-section; that is, the angles which ridge sides make at their crests have been increased to obtuse angles. "Hills" are meant to suggest that the land form is composed of numerous eminences of moderate relief and of smooth and rounded contours. Except in so far as it suggests reduction from a higher and more rugged form, the term "beveled hills" is intended to be descriptive, and is not meant to suggest the agencies by which reduction was effected.

GENETIC SIGNIFICANCE OF REGIONAL SLOPES

The desirability of a subdivision of this kind is that it will stimulate the gathering of data on the slopes of old erosion surfaces, and that it places definite limits on the term "peneplain." The value of such data and of such a restriction have been referred to before. An added argument in its favor is that the subdivision is based upon a factor which is of genetic significance in the development of land forms. For the slopes of a topographic form are not only one of the results of its development, but the amount of slope

[1] R. S. Tarr, "The Peneplain," *Am. Geol.*, XXI (January–June, 1898), 351–70.

present is also a factor in the rate of its further development. Moreover, the rate of development decreases so rapidly with decrease of slope that "beveled hills" are probably chronologically closer to forms in early maturity than to peneplains.

It is proposed in the following section to give proofs for the hypothesis that the rate at which a land surface progresses through the geographic cycle is dependent on its average regional slope, and that its progress becomes slower as the slopes become less. This hypothesis has of course been accepted by physiographers[1] for a long time, and is discussed only because of the emphasis placed in this paper on "average regional slope" and because the writer has found no presentation of evidence to prove this hypothesis.

The products of erosion in the normal geographic cycle are practically all removed from the land by streams. The rock waste is moved downstream partly as débris and partly in solution, and, if one could compare the amount of load carried by the streams on any land form during two stages of its progress, when average slopes were known, a measure would be furnished of comparative changes in the rate of erosion as the geographic cycle progresses toward old age.

The load consists of débris dragged along the stream bed, débris carried in suspension, and rock matter carried in solution, each of which will be considered in the order named.

A series of experiments have been made by Gilbert[2] on the relations between the load of débris that a stream can drag along its bed, and its slope.

The experiments proved that the quantity of load dragged by a stream varies in a complex manner with a set of controlling factors—such as slope of stream bed, discharge of water per second, fineness of débris, and form of stream channel. The changes, in amounts carried, vary at a different rate for each of the factors concerned. Under the conditions of the laboratory, the load dragged along the stream bed varied with the slope, but at a greater rate.

[1] W. M. Davis, "The Peneplain," *Am. Geol.*, XXIII (January–June, 1899), R. S. Tarr, "The Peneplain," *ibid.*, XXI (January–June, 1898), 354, 365.

[2] G. K. Gilbert, "The Transportation of Débris by Running Water," *U.S.G.S., Professional Paper No. 86*, pp. 10–54, 120, 121.

If, for instance, the slope, expressed in percentage of fall to horizontal distance, was doubled, the load dragged was, in the experiments, increased three to more than tenfold. Conversely as the slope decreased, the load decreased, but at a greater rate.

The load carried in suspension is partly a function of the stream's velocity, and depends partly upon the fineness and amount of débris supplied. In experiments made on streams without load, the velocity was found to vary approximately as the 0.3 power of the slope, and the 0.25 power of the discharge.[1]

The size of pebbles which can be carried in suspension varies as the fifth power of the velocity; that is, if velocity were unaffected by the addition of débris, it would vary approximately as the $\frac{5}{3}$ power of the slope. Velocity is diminished by suspended matter, but not enough to make the factor of $\frac{5}{3}$ less than unity. It is probable that in the majority of cases the grading of débris supplied to a stream is such that, if the slope be increased, the maximum load of suspended material carried by a stream will increase at a rate comparable to the rate of increase of the size of débris carried; that is, it will increase at a slightly greater rate than the increase in slope. Conversely if the slope be decreased, the maximum load carried in suspension will be decreased but at a greater rate than the slopes.

If discharge and fineness of débris supplied remain the same, therefore, both the maximum load dragged along a stream bed and that carried in suspension decrease at a greater rate than the slope, and the difference in the rate of decrease of the two functions becomes greater as the slopes decrease. This law of variation is applicable to natural streams as well as to those in the laboratory.[2]

But changes in discharge and fineness of débris as old age progresses, both tend to reduce further the load carried. For the rainfall on a land form, the size of a geographic unit is likely to decrease as the land becomes lower, and the proportion of runoff to rainfall will also decrease so that the discharge of the streams would decrease. The débris supplied to the streams, moreover, becomes

[1] *Ibid.*, 225. Discharge is defined as the number of cubic feet of water passing a given point per second.

[2] Gilbert, *op. cit.*, p. 233.

finer with old age and its increasing depth of soil. But suspended matter added to a stream retards its velocity, and the rate of retardation becomes greater as the débris becomes finer.[1] Hence as the slopes became lower, both the factors of decreased discharge and increased fineness of débris would help to a further and more rapid rate of decrease of maximum load carried.

Obviously also the amount of creep and wash of débris down hillsides into the stream beds is smaller on gentle than on high slopes. The rate at which a land form is worn down by mechanical erosion must therefore diminish very rapidly as the slopes decrease. On the other hand, lower slopes may aid chemical erosion, in that more rain water is absorbed and the solution of the rock materials near the surface is increased. Chemical erosion must, however, be a very small factor in the wearing down of a land surface, for the matter dissolved in river waters is derived from surface rocks in the process of weathering, and the greater bulk of the rocks at the surface lose on an average less than one-third of their original weight by the process of solution when weathering is complete. Moreover, part or all of this loss is compensated for, both in weight and in bulk, by gains in the form of oxygen, water, and carbon dioxide obtained from the atmosphere, and recombined as insoluble mineral products in the residual soil.[2]

If the average slopes of a land surface, therefore, be reduced in the progress of the geographic cycle from, say, 4 per cent to 2, the rate of reduction of the land surface by erosion will be less than one-half what it was before, and as the slopes decrease, the process becomes slower and slower.

The final stages of old age in which the surface is reduced to slopes as low as one-tenth of 1 per cent must therefore represent a very much longer period of time than the stage of maturity or of early old age. Chronologically, therefore, "beveled hills" are probably closer to land forms in early maturity than to "peneplains," and for that reason alone the subdivision proposed in this paper should be justified.

[1] Gilbert, *op. cit.*, p. 228.

[2] F. W. Clarke, "The Data of Geochemistry," *Bull. 491, U.S.G.S.*, pp. 462 and 465.

OBJECTIONS TO A SUBDIVISION BY AVERAGE REGIONAL SLOPES

The objections which may be urged to a subdivision of this kind are: (*a*) that it is an arbitrary one; (*b*) that the slopes on a land form vary widely, and two observers may come to different conclusions regarding it; (*c*) that it requires a greater amount of detailed field and office work than is necessary when the average slopes are not taken account of.

a) The subdivision is arbitrary, for as far as we know there is no distinct change in the cycle at either of the two limiting points of 2 and 3 per cent, which is placed on the two type forms proposed here. Moreover, it is probable that there are old erosion surfaces to represent all stages of average regional slope from 6 per cent to less than one-tenth of 1 per cent, and there may be as many examples lying between the two types proposed as within the limits of the peneplain type.

A parallel might be drawn between the classification of igneous rocks and the subdivision proposed here. In 1886 or thereabouts, when geologists of the United States Geological Survey found large areas in the Sierra Nevada Mountains underlain by intrusive masses of approximately similar composition lying between the quartz-diorite and granite families, they suggested the name granodiorite for them. Thirteen years later Lindgren[1] proposed definite limits for the "granodiorite" family in regard to both its chemical and mineralogical composition. The bulk of the rock masses referred to in the Sierras, and later found to occupy great areas in Canada, fall within the limits proposed by him. His quantitative restriction of the term granodiorite is therefore justified, for it represents a natural group of rocks. The term gains stability, moreover, because of the occurrence of this group within a definite and accessible region.

This definition of granodiorite is of great value to petrographers because it furnishes a clear-cut standard of comparison and datum point within the scheme of classification. The occurrence of rocks intermediate in composition between granodiorite and granite on the one hand, or granodiorite and quartz-diorite on the other, does

[1] Waldemar Lindgren, "Granodiorite and Other Intermediate Rocks," *Am. Jour. Sci.*, IX (1900), 269–82.

not detract from the usefulness of the quantitative definition of the family, but rather adds to the necessity of such a definition. In the same way the term "beveled hills" proposed here represents a land form which actually occurs over the known portion of a large geographic unit, the Interior Plateaus of British Columbia, and the quantitative limits proposed for the type are those measured upon the land form in question. The value of the establishment of a subdivision centering about a quantitatively defined physiographic type should also not be seriously impaired by the occurrence of numerous intermediate forms.

b) The slopes on a land form vary widely, and an accurate average is not easily obtained. Variation in slope will cause trouble only in old surfaces of fairly high relief, that is, in the "beveled hills" type. In the work in the Interior Plateaus, it was found that the greater part of the surface within areas of about 200 square miles lay between 3 and 6 per cent, and where slopes of a mile or more in length varied greatly from the general average they occurred over small areas. By estimating the relation of the size of these areas to the whole, irregularities of slope were calculated into the whole, and found to change the general average very slightly. If care is taken first carefully to separate forms due to different cycles, and then to note the frequency of the occurrence of irregularities varying from the average, the final results will be found to be fairly consistent.

In land of lower relief, that is, in the peneplain division, the results will be found to agree much more closely for the variation in slope is very much less.

c) The amount of field work is greater than is necessary when slopes are not measured.

This is true even when the measurements are made on topographic maps, for in order to appreciate the meaning of the forms shown on a topographic map it is necessary that one examine them closely at first hand. The extra time and energy which physiographers will of necessity have to spend in traversing old land surfaces before they can obtain data upon the nature and extent of their slopes is one of the best arguments for the adoption of this classification instead of an objection to it. The geologist knows

that rocks must be cracked if results are to be obtained, and the physiographer who depends largely upon distant views will miss a great deal of the detail which helps to prove or disprove field hypotheses.

SUMMARY

In the study of the physiographic development of the Interior Plateaus of British Columbia, certain characteristics commonly accepted as criteria for peneplanation were found well developed upon an erosion surface with regional slopes of 3 to 6 per cent.

Stress is laid on the value of the study and measurement of the regional slopes of old erosion surfaces, and a quantitative subdivision of old erosion surfaces on the basis of their average regional slopes is suggested. Regional slope is defined as the general slope of the land toward main drainage lines, and an outline is given of the methods of measuring regional slopes, as followed in the work on the Interior Plateaus of British Columbia.

The determination of the regional slopes of a land form is of value in furnishing clews to the agencies which have affected its development, and in separating the products of the different cycles of erosion through which it may have passed. The measurement of regional slopes is essential if a land surface is used as a datum for the measurement of movements of the earth's crust. For if such measurements are not made, an uplifted old erosion surface is very likely to be considered of much lower relief than is actually the case. Such an assumption leads to serious errors in estimates of the manner and extent of movements of the crust. It is caused partly by optical illusions, and partly from the fact that the characteristic flat horizon lines and the discordance of topography and structure which prevail over old erosion surfaces of plainlike form are also found well developed upon surfaces of much greater relief.

It is proposed that old erosion surfaces be divided into two central types "peneplains" and "beveled hills." Peneplains are to be characterized by average regional slopes up to 2 per cent by discordance between topography and structure, by the absence of local irregularities of slope, such as cliffs and flat areas, and by deep soil covering.

"Beveled hills" are old erosion surfaces with dominant discordance between topography and structure, with a general absence of irregularities of slope, and with deep soil covering. In addition, one may expect to find on them the accessory characters of partial accordance between topography and structure and occasional cliffs and flat areas. It is proposed that the term be confined to forms with average regional slopes of from 3 to 6 per cent and that the upland portion of the Interior Plateaus of British Columbia be considered the type of this land form.

The subdivision is desirable because it will stimulate the measuring of regional slopes and thus assist in working out the physiographic development of the surface and diastrophic movements of the crust after its formation. It is not contrary to the accepted hypotheses of the genesis of a land form through the normal cycle of erosion, for the degree of slope is a factor in the manner, as well as the rate of development, of an erosion surface.

The objections to the subdivision are that it is arbitrary, that a true average of the regional slopes on a land form are hard to get, and that it involves more field and office work than are otherwise necessary. The objections are met in the following manner.

The type form "beveled hills" is represented by an old erosion surface, which is found throughout the southern portion of a large geographic unit, the Interior Plateaus of British Columbia. The subdivision is therefore not entirely arbitrary. The difficulty of obtaining a true average of the regional slopes on a land surface can be met by taking account of the relative area occupied by slopes departing from the general average. It is thought, finally, that the extra field work involved in traverses over the region will be of advantage in calling attention to details of physiographic interest which can be obtained in no other way.

It is well to repeat here that the object of this paper is first of all to point out the importance of the study and determination of regional slopes on old erosion surfaces, and that the particular form of subdivision proposed is not considered final.